A Study on Pavement Surface Brightness as a Performance Indicator

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ABSTRACT

The law on the promotion of quality assurance in public works was enacted in April, 2005 in Japan. According to this law, when the government agencies order public works, they have to adopt a comprehensive evaluation bidding system. The system works as such that not only the cost but also the technical proposals by the contractor in terms of the performance indexes specified by the owner are to be evaluated.

In the case of pavement works under the comprehensive evaluation system applied, the owner has more often specified the "smoothness" and the "tire/road noise" as the performance indexes.

The case has been very few, in which the “pavement surface brightness” was adopted as a performance indicator.

The authors voluntarily made a study on this index in the construction of a colored asphalt pavement on a National road in Akita Prefecture.

The target value of "Surface brightness" was set at 55 or over referring to the performance specification previously applied in a different project. Various measures were taken to improve the "surface brightness" including the mixing design of the asphalt mixture and the paving method on site.

This paper reports a study on the "surface brightness" as a performance indicator and its measurements which satisfactorily exceeded the target value.

1. INTRODUCTION

The law regarding the promotion of quality of public works was enforced in April, 2005. This law specifies the application of a comprehensive evaluation system as the order system of the public works, in which bidding price and technical proposals as to the specified performance index are evaluated. As for the performance index, six indicators were shown in “The Technical Standards for Pavement Structure" which was compiled in 2001. Then, in March, 2008, nine indicators for the roadway and marginal strip and five for the sidewalk were introduced in "Additional Volume to The Pavement Performance Evaluation Methods,” (hereafter referred to as “Additional Evaluation Method”).

“Surface brightness", which is one of the nine indicators and few construction projects have specified in the past, was taken up in this study. Investigations were made on the asphalt mixtures in laboratory and verification was made at a construction site.

The laboratory examination was conducted on bright colored stone mastic asphalt mixtures (hereafter referred to as bright colored SMA mixture) consisted of, among others, white artificial aggregates (hereafter referred to as white aggregates), white pigments and de-colorization binder. The laboratory tests were aimed at finding out the relationships between the brightness and the amount of

white aggregates and white pigments. Based on the test results, measurements and evaluation of the surface brightness were made in a road tunnel where a bright color SMA mixture was applied.

2. Research procedure

(1) Examination flow

Figure 1 illustrates the flow of this study on the bright colored SMA mixtures from the laboratory tests to the verification at a construction site.

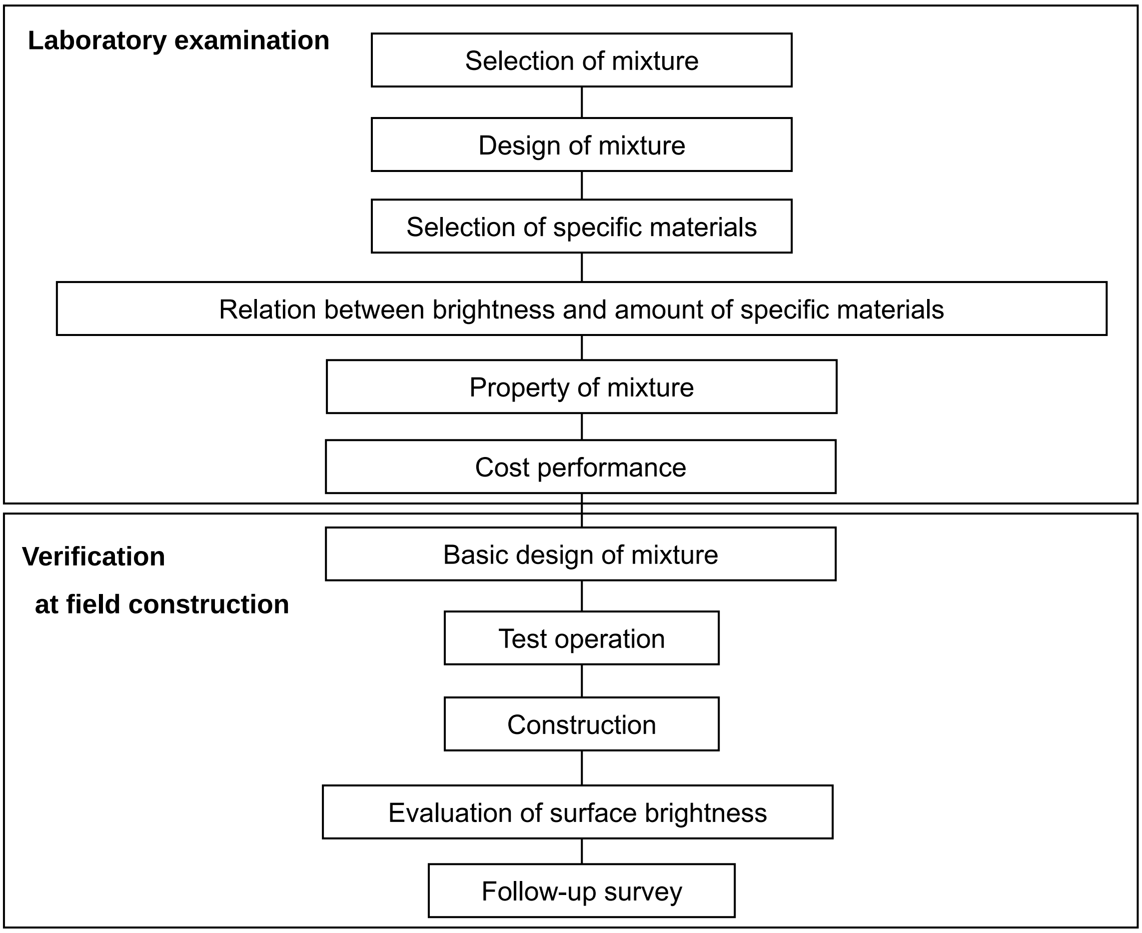


Figure 1. Examination flow

(2) Selection of mixture

The laboratory examination focused on an asphalt mixture to be used in a tunnel. The asphalt mixture selected was a stone mastic asphalt mixture (hereafter referred to as SMA mixture). The reasons were, and are, that the mixture is excellent in rutting resistance, wear resistance and impermeability and is widely used in Japan including cold and snowy areas.[1)]

3. Laboratory examination

(1) Proportion of aggregates

The design of SMA mixture in the grading and asphalt content was based on a targeted percentage of air voids.

Table 1 shows three types of grading within the range for the surface course specified as Grading I in “The Pavement Construction Manual”.[2)] And then, a polymer-modified asphalt Type II (hereafter referred to as Type II Polymer-modified asphalt) was used as a binder and the optimum asphalt content was set to make the percentage of air voids to be 3 %.

Marshall specimens were made for every grading and the middle grading was adopted by looking at the luster and texture of the specimen.

Table 1. Grading of SMA mixture

Materials		Proportion of Aggregate (%)			
		Upper grading	Middle grading	Lower grading	Grading range
Crushed stone(13-5mm)		63	65	70	-
Crushed stone(5-2.5mm)		10	9	6	-
Screenings		7	7	6	-
Fine sand		8	7	6	-
Mineral filler		12	12	12	-
Combined grading					
Weight percentage of fraction passing a sieve (%)	19mm	100.0	100.0	100.0	100
	13.2mm	98.5	98.4	98.3	-
	9.5mm	76.1	75.4	73.5	95-100
	4.75mm	37.4	35.7	31.4	20-40
	2.36mm	27.8	26.8	24.8	20-35
	0.6mm	21.9	21.0	19.7	-
	0.3mm	16.1	15.9	15.3	10-20
	0.15mm	13.2	13.2	13.0	-
	0.075mm	10.8	10.7	10.6	8-13

(2) Selection of special materials

As shown in Table 2, special materials were used in the laboratory examination in order to improve the brightness of SMA mixture, rutting resistance and wear resistance.

Table 2. Specific material

	Material	Remarks
Aggregate	White aggregate	Artificial white aggregate
Pigment	White pigment	Titanium-oxide
Binder	De-colorization binder	Binder equivalent to Type II modified asphalt
Plant fiber	-	Improving rutting and wear resistance

(3) Design of mixture

The optimum de-coloring asphalt content was determined based on the percentage of air voids selected as the standard for the middle grading mixture. In the study, the optimum asphalt content for four types of the mixtures were determined ;two set of two types of mixtures with and without plant fibers, and with and without part of 6th sized crushed stone (13-5mm) replaced by white aggregates. Table 3 shows the combination of the special materials.

Table 3. Combination of special materials

Mix proportion No.	Binder	Coarse aggregate	Plant fiber
No.1	De-colorization binder (Binder equivalent to Type II modified asphalt)	Single-sized crushed stone	With
No.2			Without
No.3		White aggregate replacing part of crushed stone(13-5mm)	With
No.4			Without

(4) Measurement of brightness

1) Target of road surface brightness

As shown in Table 4, “The Additional Evaluation Method” illustrates standard values of brightness for continuous lighting, limited lighting and tunnel lighting. The values in the parentheses in the table are the average conversion coefficients of illuminance, which convert the average surface brightness to the average surface illumination. They are quoted from “The installation standards for highway lighting facility and the guidance".[3] There is good correlation between the brightness and the average conversion coefficient of illuminance, and the average conversion coefficient of illuminance and the brightness can be calculated using the estimated equation (1) and (2), respectively.

Table 4. Example of brightness standard[4]

Road surface	Brightness (Average conversion coefficient of illuminance)	
	Continuous lighting or Local lighting	Tunnel lighting
Asphalt	51(15)	47(18)
Concrete	61(10)	55(13)

$$K = 136919 \cdot L^{*-2.3163} \quad (1)$$

$$L^* = 165.017 \cdot K^{-0.43172} \quad (2)$$

where, K: Average conversion coefficient of illuminance (Lx/ (cd/m^2))

L*: Brightness

There are cases in which the conversion factor was selected as a performance indicator in pavement construction projects ordered by the Hokuriku Regional Development Bureau, the Ministry of Land, Infrastructure, Transport and Tourism in 2003 and 2004. The standard value of the conversion factor was set equal to or under 18(Lx/cd/m^2).[5] The evaluation was made on the conversion factor calculated by the equation (1) and/or (2) with the measured brightness. When converted, the standard value of brightness in this case turns out to be equal to or over 47.

The surface brightness was selected as a performance indicator in laboratory tests and its target value was set to be equal to or more than 55, which is comparable to the brightness required of the concrete pavement. Also, the evaluation of the surface brightness was based on "Additional Evaluation Method” and the measurement was made in accordance with “The Method for Measuring Brightness Using Colorimeters", which is specified in the guidebook.

2) Relation between white pigments and brightness

White pigments were added to the mixtures denoted as Mix proportion Nos. I and II in Table3, and the measurements of brightness were made as related to the amount of white pigments. In this case, part of mineral filler was replaced by the white pigments.

As shown in Photo 1 and based on the test results, it was concluded that the brightness became higher with increased amount of the additive, but it didn't change much when the amount exceeded 3 %.

Upper: With plant fiber, Lower: Without plant fiber
From left, Addition of white pigment 0%, 1%, 3%, 5%
Photo 1. Specimen with white pigments

3) Relation between white aggregate and brightness

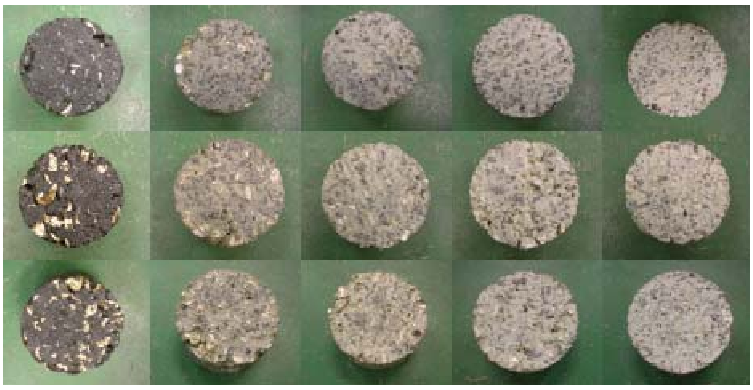
As for the mixtures of Mix proportion Nos. III and IV, the relationship between the amount of the white aggregates and the brightness was studied. It was clear that the increases of the white aggregates did not contribute to the extent of brightness when compared with the case of the white pigments. The reason seems that the improvement in brightness caused by the white aggregates is not uniform as in the case of white pigments and appears only on the surface with them exposed as shown in Photo 2.

From left, Addition of white aggregate 10%, 30%, 50%
Photo 2. Specimen with white aggregates

4) Relation between amount of white aggregate and brightness when white pigments added

Additional studies were conducted on the mixtures discussed on in the previous section 3. (4) 3) by adding white pigments. As a result, it became clear that the mixture with only white aggregates added by up to 50% could not meet the target value of 55 while the mixture with only about 2% of white pigments safely met the target. Also, confirmations were made that both additives contributed to the improvement of brightness. They did not deny their effect each other as shown in Photo 3. It is possible to conclude that the addition of white pigments is more influential than that of white aggregates in the

brightness. And the addition of white pigments by about 2% will be enough to reach the extent of the brightness provided by the concrete pavement.



Upper: Addition of white aggregate 10%
Middle: Addition of white aggregate 30%
Lower: Addition of white aggregate 50%
From left, Addition of white pigment 0%, 0.5%, 1%, 1.5%, 2.0%
Photo 3. Specimen with white pigments and white aggregates

(5) Property test of mixture

Tests of the effect caused by white pigments and white aggregates on the mixture property were conducted. The mixture used in the tests was mixed with de-colorization binder, white pigments (2 %), white aggregate (30 %) and plant fiber (0.3 % as against the rest of the mixture) and expected to have sufficient brightness. The dynamic stability of bright color SMA mixture by the wheel tracking test was about 3,200 (times /mm), which met the target value (3,000 (times /mm)) of the dynamic stability specified in the Pavement Construction Manual[6)] for heavy trafficked road with design daily traffic volumes of 3,000 (vehicles/ day). It was also confirmed that the mixture without plant fiber showed a relatively lower dynamic stability. Incidentally, this type of pavement with higher brightness is likely to have better rutting resistance because the surface temperature does not rise when compared with the conventional asphalt pavement.

In addition, confirmations were made by the raveling and bending tests that the bright colored SMA pavement had a tendency in wearing resistance and flexibility to deflection comparative to that observed in ordinary SMA mixtures with modified Type II binder.
Also, the result from the raveling test indicated that the abrasion kept the brightness from decreasing by exposing the coarse-aggregates with white aggregates added.

(6) Verification of the cost effectiveness to get better brightness

Study was conducted on the cost performance in the additional use of white pigments and white aggregates.

White pigments, which are cheap in price, produced an expected effect with a little amount. On the other hand, addition of white aggregates, of which price is expensive, could not achieve the goal with a lot of them. It is possible to conclude that addition of white pigments is economically beneficial to attain the targeted brightness.

4. Verification at field construction

Verification was made at a construction site of the effect of bright color SMA mixture placed on cement concrete base course in a tunnel.

The target value of the surface brightness was set beforehand. Measurements of the brightness were made on the specimens made of the same materials used for the construction to determine the mix design of bright color SMA mixture to meet the target. Also, a test construction was executed to find out notes for attention and incorporate them into an operation standard which does not damage the surface brightness during construction works. Measurements of the surface brightness were made by the colorimeter immediately after the construction.

(1) Setting of target value for surface brightness

The brightness provided by cement concrete pavement is better than that by asphalt mixture pavement and there are many cases in which concrete pavement is selected for a tunnel section to keep the running cost of the illumination facilities lower.

Therefore, the target value of the brightness for this study was set to be equivalent to the value specified for cement-concrete pavement, 55 or more.

(2) Verification of brightness

The laboratory examination so far revealed the following;

1) The addition of white aggregates does not increase the brightness compared with white pigments, and

2) The target brightness of 55 is achievable by adding white pigments about 2 %.

In the design of SMA mixture, materials manufactured at places close to the construction site were used. The design was aimed at the middle grading in Table 1.

Next, trial mix was made, based on the relationship described in 3. (4) 4), with varied proportion of white aggregates and white pigments as shown in Table 5. Comparison of the measured brightness was made among specimens made of each mix proportion.

Table 5. Mix proportion for test elaboration

Mix proportion No.	White aggregates (%)	White pigments (%)
1	20	0
2	20	1
3	15	2
4	0	3

The result of measurement is shown in Figure 2. In this case, the measurement was made on the cut surface of the specimen assuming that the pavement surface would experience an abrasive action and its asphalt mortar would be removed after opening to traffic. The cut plane of the specimen is shown in Photo 4.

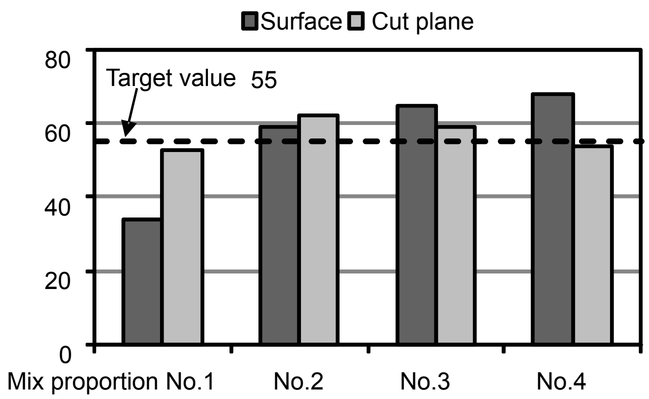


Figure 2. Mix design and brightness

Mix proportion No.2 No.3

Photo 4. Cut plane of specimen

It was again confirmed that the addition of at least 2% of white pigments would be necessary for meeting the target value. Also, it would be necessary to mix a certain amount of white aggregates in order to secure the long lasting brightness when the abrasive action was taken into account. The fact that the brightness of mix proportion II and III was almost identical would suggest the addition of white aggregates by 15% necessary.

Based on the result mentioned above and taking into consideration the economical aspect of the materials discussed in 3. (6), mix proportion III was adopted for the field mix. The proportion of the materials used for the mixture is shown Table 6.

Table 6. Mix proportions

Materials	Proportion (%)	Remarks
Crushed stone(13-5mm)	44	-
Crushed stone(5-2.5mm)	13	-
Coarse sand	12	-
Fine sand	5	-
Mineral filler	9	-
White aggregate	15	Equivalent to sized crushed stone(13-5mm)
White pigment	2	Equivalent to mineral filler
Plant fiber	0.3	Adding to total
Total	100.3	-

(3) Test operation

Before the actual construction, a test operation was executed by using a series of paving machine and the mixture composed of the materials shown in Table 6. As a result, it became evident that the following practices would be important to keep the brightness from falling;

1) Depending on the surface temperature, the use of pneumatic-tire roller is to be avoided since it would cause the pavement surface to become black,
2) Compaction by macadam roller and horizontal-vibration roller is recommended and pure water is to be distributed for anti-sticking, and
3) The hopper, bar feeder and the part of asphalt paver which is in contact with the paved surface are to be kept clean.

(4) Actual construction

The construction project is summarized in Table 7. And Photo 5 shows the paving operation. The important notes obtained from the test operation worked very well as is seen from Photo 6 which shows the completed surface immediately after the construction work.

Table 7. Summary of construction project

Items	Implementation contents
Location	Prefectural road No.59(Akita Prefecture)
Time of construction	2007.8
Design daily traffic volume of heavy vehicles	250 to 999
Underling base	Cement concrete base
Repair section	Surface course : thickness=3cm Leveling course : thickness=3cm
Paved area	3,700m^2(width=7.5m , length=492m)

Photo 5. Paving operation

Photo 6. Pavement surface immediately after construction

(5) Evaluation of surface brightness

The measurement of brightness by the colorimeter was made after the construction and the result is sown in Table 8 for evaluation.

Also, reliability was analyzed assuming the distribution of population was normal based on the relationship between the average value and the standard deviation of the brightness.

As a result, it was seen that the target value of 55 was achieved with 96.8% of probabilities. In the calculation, the coefficient alpha in Equation 3 below turned out to be 2.14.

It can be concluded that the bright color SMA mixture can produce a pavement which is comparable to or better than concrete pavement in terms of the surface brightness.

Table 8. Evaluation of road brightness

Items	Value	Target value
Number of the measurement points (Xi)	10	-
Average of brightness (X)	57.7	55
Standard deviation (σ)	1.26	-

$$\text{Target value of brightness} = X - \alpha * \sigma \qquad (3)$$

where, α: random variable in standard normal distribution table

(6) Follow-up survey

A follow-up survey was conducted after one year of service. The result of the brightness measurement and the status of the pavement are shown in Figure 3 and Photo 7, respectively.

The surface brightness decreased about 20 % when compared with the time the construction. No scattering of aggregates and soiling were observed and the pavement surface stayed in a good condition.

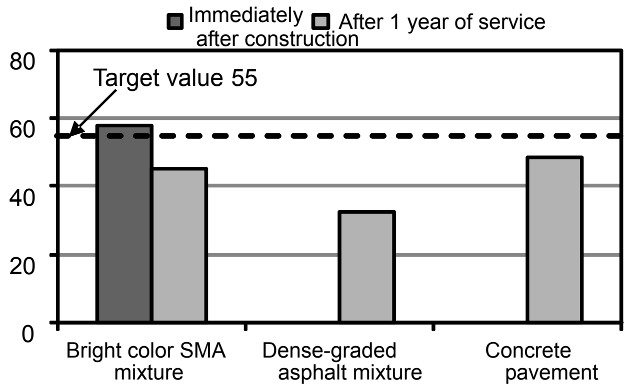


Figure 3. Brightness after one year of service

Photo 7. Pavement surface after one year of service

5. Summary

Findings from the laboratory examination and verification at the field are summarized as follows;

(1)Laboratory examination

1. Although the improving effect of increased amount of white aggregates by up to 50% on the brightness is small, a long lasting effect by the exposed aggregates can be expected after opening to traffic.
2. The addition of white pigments by about 2% can secure the standard of the brightness provided by concrete pavement (equal to or over 55).
3. The use of plant fiber is effective in the improvement of rutting resistance.
4. The wear resistance and the bending strength of bright color SMA mixture were identical to those of ordinary SMA mixture using Type II modified asphalt binder.
5. The improvement of the brightness can be expected more by the addition of white pigments than white aggregates. The former is also better than the latter in terms of the price.

(2) Verification at construction site

1. The asphalt mortar is gradually removed by the traffic resulting in the exposed aggregates so that it was confirmed that the combined use of de-coloring asphalt, white pigments and white aggregate is effective.
2. It is necessary to make sure, by conducting a test operation, for example, of the application of pneumatic tire roller at the time of paving.

3. Pure water is effective for rolling/compacting machine in anti-sticking.
4. Parts of construction machine which are in touch with the mixture and/or the paved surface are better to be cleaned occasionally.

6. Conclusions

In this study of the surface brightness, it was confirmed that bright color SMA mixture met the target value. A follow-up study after one year of service revealed the decrease of the brightness by about 20 % when compared with the time of construction. Incidentally, the comparison of the decline in the brightness at wheel path and the rest of the roadway indicated that the former experienced a decrease than the latter due to the wearing effect by the rolling tires.

In the future, further study is under planning on the sustainability of the pavement and the durability of the brightness in order to confirm the effectiveness of this type of pavement.

Lastly, the authors would like to acknowledge the officials of Funakawa Port Office, Construction and Transportation Department, Akita Prefecture, for their cooperation in this project.

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